ISBN 978-9940-611-12-5

COAST
INTERNATIONAL CONFERENCE ON ADVANCES IN SCIENCE AND TECHNOLOGY

V INTERNATIONAL CONFERENCE ON
ADVANCES IN SCIENCE AND TECHNOLOGY

PROCEEDINGS COAST 2026

FACULTY OF MANAGEMENT HERCEG NOVI

HERCEG NOVI, MONTENEGRO

09 JUNE – 13 JUNE 2026

FAKULTET ZA MENADŽMENT
HERCEG NOVI

V INTERNATIONAL CONFERENCE ON
ADVANCES IN SCIENCE AND TECHNOLOGY

BOOK OF PROCEEDINGS

HERCEG NOVI, 09 JUNE – 13 JUNE 2026

V INTERNATIONAL CONFERENCE ON ADVANCES IN SCIENCE AND TECHNOLOGY
COAST 2026

Organizer

Faculty of Management Herceg Novi

Co-organizers

Univerzitet u Nišu
Građevinsko arhitektonski fakultet

Univerza v Mariboru
Fakulteta za turizem

Univerzitet Union

St. Petersburg State University of Film and Television

fpep Bar

PMC Fakultet za projektni i inovacioni menadžment
EDUCONS

VUB

AUE

Висока школа за пословну економију и предузетништво

MSS Visoka škola modernog biznisa

Partners

ProStud/o.me

herceg novi

BOOK OF PROCEEDINGS

Publisher:
Faculty of Management Herceg Novi

Editor-in-Chief:
Djordje Jovanović, PhD

Editors:
Irena Petrušić, PhD
Jovana Jovanović, PhD
Ivan Stevović, PhD

Design and Computer processing:
Zvonko Perušina, BSc

CIP - Каталогизација у публикацији
Национална библиотека Црне Горе, Цетиње

ISBN 978-9940-611-12-5
COBISS.CG-ID 39796484

BOOK OF PROCEEDINGS

Organizing Committee:

General Chairs of the Committee: Djordje Jovanović, PhD **(MNE)**, Olivera Jovanović, PhD **(MNE)**
Chairs of the Committee: Irena Petrušić, PhD **(MNE)**, Jovana Jovanović, PhD **(MNE)**
Coordinators: Milena Djukanović, PhD **(MNE)**; Nikša Grgurević, PhD **(MNE)**; Mihailo Jovanović, PhD **(MNE)**
Bulatović Dragan, PhD **(MNE)**; Djurić Dušan, PhD **(SRB)**; Kartseva Aleksandra, PhD **(RUS)**; Klarić Dragan, PhD **(MNE)**; Koprivica Suzana, PhD **(SRB)**; Koščak Marko, PhD **(SVN)**; Milošević Danijela, PhD **(SRB)**; Dr Stević Ivan **(SRB)**; Deretić Žaklina, MSc **(MNE)**; Milanović Duško, MSc **(MNE)**; Koprivica Stefan, MSc **(SRB)**; Koprivica Milica, MSc **(SRB)**; Savić Dragana, MSc **(MNE)**; Savić Ivana, MSc **(MNE)**; Dragović Andrea, BSc **(MNE)**; Perušina Zvonko, BSc **(MNE)**

Scientific and Program Committee

Abramović Nikola, PhD **(MNE)**, Faculty of Business Economics and Law, Bar,
Aničić Jugoslav, PhD **(SRB)**, University "Union - Nikola Tesla", Belgrade
Biočanin Vladimir, PhD **(SRB)**, Faculty of Medical Sciences, University of Kragujevac
Blagojević Marija, PhD **(SRB)**, Faculty of Technical Sciences, University of Kragujevac, Čačak
Božilović Zvonimir, PhD **(SRB)**, University "Union - Nikola Tesla", Belgrade
Brumen Boštjan, PhD **(SVN)**, Faculty of Tourism, University of Maribor
Bulatović Dragan, PhD **(MNE)**, Faculty of Management, Herceg Novi
Cogoljević Vladan, PhD **(SRB)**, Faculty of Business Economics and Entrepreneurship
Dimitrova Vesna, PhD **(MKD)**, Cyril and Metodius University, Skopje
Djoković Goran, PhD **(SRB)**, Modern Business School, Belgrade, Serbia
Djukanović Milena, PhD **(MNE)**, Faculty of Electrical Engineering, University of Montenegro, Podgorica
Djurašević Silvana, PhD **(MNE)**, Faculty of Management, Herceg Novi
Djurić Djuro, PhD **(MNE)**, Faculty of Business Economics and Law, Bar
Djurić Dušan, PhD **(SRB)**, Faculty of Medical Sciences, University of Kragujevac
Djurić Sonja, PhD **(ESP)**, University of Valencia, Spain
Djurović Sandra, PhD **(MNE)**, Faculty of Business Economics and Law, Bar
Dong Wang, PhD **(CHN)**, Mechanical Engineering at Shanghai, Jiao Tong University
Dupláková Darina, PhD **(SVK)**, Technical University of Kosice,Faculty of Manufacturing Technologies with a seat in Prešov, Institute of Advanced Technologies, Prešov, Slovakia
Grgurević Nikša, PhD **(MNE)**, Faculty of Management, Herceg Novi
Holzner Johannes, PhD **(DEU)**, Department of Agriculture, Food and Nutrition, University of Applied Sciences Weihenstephan-Triesdorf, Weidenbach
Jaganjac Jamila, PhD **(BIH)**, Faculty of Business Economics, University Vitez, Travnik
Jakopin Edvard, PhD **(SRB)**, University "Union - Nikola Tesla", Belgrade
Jovanović Jovana, PhD **(MNE)**, Faculty of Management, Herceg Novi

BOOK OF PROCEEDINGS

Jovanović Mihailo, PhD **(MNE)**, Faculty of Management, Herceg Novi
Jovanović Djordje, PhD **(MNE)**, Faculty of Management, Herceg Novi
Jovanović Olivera, PhD **(MNE)**, Faculty of Mechanical Engineering, University of Montenegro, Podgorica
Jovković Ljiljana, PhD **(SRB)**, MB University, Belgrade
Jurakić Marko, PhD **(HRV)**, Vimal Academy for Human Resources Development, Zagreb
Karabegović Edina, PhD **(BIH)**, Technical Faculty of the University of Bihać
Karabegović Isak, PhD **(BIH)** Academician of Academy of Sciences and Arts of BIH
Kartseva Aleksandra, PhD **(RUS)**, University at the Inter-Parliamentary Assembly EurAsEC, St. Petersburg
Klarić Dragan, PhD **(MNE)**, Faculty of Management, Herceg Novi
Koščak Marko, PhD **(SVN)**, Faculty of Tourism, University of Maribor
Kostić Vasilije, PhD **(MNE)**, Faculty of Management, Herceg Novi
Koprivica Suzana, PhD **(SRB)**, University "Union - Nikola Tesla", Belgrade
Liehuang Zhu, PhD **(CHN)**, Beijing Insitute of Technology, Beijing
Lukić Nikolić Jelena **(SRB)**, Modern Business School, Belgrade, Serbia
Maksimović Sekulić Nina, PhD **(SRB)**, Modern Business School, Belgrade, Serbia
Mamula Nikolić Tatjana, PhD **(SRB)**,Metropolitan University,Belgrade,Serbia
Markuz Ana, PhD **(HRV)**, Libertas International University, Zagreb, Croatia
Martinović Srdja, PhD **(MNE)**, Faculty of Law, University of Montenegro, Podgorica
Mašović Azemina, PhD **(MKD)**, Integrated Business Faculty, Skopje
Mihajlović Milan, PhD **(SRB)**, Modern Business School, Belgrade, Serbia
Milošević Danijela, PhD **(SRB)**, Faculty of Technical Sciences Čačak, University of Kragujevac
Mirović Dejan, PhD **(MNE)**, Faculty of Business Economics and Law, Bar
Nikolić Ristić Dragana, PhD **(SRB)**, Metropolitan University,Belgrade,Serbia
Novićević Rajko, PhD **(MNE)**, Faculty of Business Economics and Law, Bar
Ostojić Bojana, PhD **(SRB)**, Faculty of Project and Innovation Management, Belgrade
Pavlović Vladan, PhD **(SRB)**, Faculty of Economics, University of Pristina
Pepić Siniša, PhD **(GBR)**, Apsley Business School, London
Petrušić Irena, PhD **(MNE)**, Faculty of Management Herceg Novi
Pločo Maja, PhD **(BIH)**, Faculty of Law, University Vitez, Travnik
Regazzoni Francesco, PhD **(CHE)**, Università della Svizzera italiana, Lugano, Switzerland
Rusakov Arkady Yurievich, PhD **(RUS)**, Doctor of Philosophy, Professor, Department of Project Activities in Cinematography and Television, Saint Petersburg State Institute of Film and Television, Saint-Petersburg
Sadlak Jan, PhD **(BEL)**, IREG Observatory on Academic Ranking and Excellence, Brussels
Sarić Branko, PhD **(SRB)**, Faculty of Technical Sciences, University of Kragujevac
Savić Gajić Ivana, PhD **(SRB)**, Faculty of Technology, University of Nis
Stevović Ivan, PhD **(SRB)**, Innovation Center of the Faculty of Mechanical Engineering, University of Belgrade
Trajković Slaviša, PhD **(SRB)**, Faculty of Civil Engineering and Architecture, University of Niš
Virijević Jovanović Saša **(SRB)**, Modern Business School, Belgrade, Serbia
Vukasović Vlado, PhD **(MNE)**, Faculty of Management, Herceg Novi

BOOK OF PROCEEDINGS

Vuković Adrijana,PhD **(SRB)**, MB University,Belgrade,Serbia
Xiaoqin Sun, PhD **(CHN)**, Changsha University of Science and Technology, Changsha

NOTE:

The authors have full responsibility for the originality and content of their own papers.

COMPARATIVE ANALYSIS OF GREEN SYNTHESIS OF SILVER, ZINC AND COPPER NANOPARTICLES USING PLANT EXTRACTS

Ana S. Kesić[1], Katarina M. Marković[1], Mirjana G. Grujović[1], Jelena S. Katanić Stanković[1]
[1]Institute for Information Technologies Kragujevac, University of Kragujevac, Liceja Kneževine Srbije 1A, 34000 Kragujevac, Serbia

Corresponding author e-mail address: akesic@uni.kg.ac.rs (Ana Kesić)

ABSTRACT:
Green synthesis of metal nanoparticles using plant extracts represents an environmentally friendly and sustainable approach for the preparation of nanomaterials with diverse applications. This paper presents a comparative analysis of the green synthesis of silver, zinc, and copper nanoparticles, with particular emphasis on differences in formation mechanisms, particle characteristics, stability, and potential application fields. The analysis is primarily based on the authors' own experimental results, including both published and unpublished studies, supported by relevant literature data.
Nanoparticle formation was monitored by UV–Vis spectroscopy, while interactions between plant biomolecules and nanoparticle surfaces were examined using FTIR analysis. Particle morphology and size were determined by SEM and TEM techniques. The results indicate that green synthesis predominantly leads to the formation of elemental silver nanoparticles, whereas zinc and copper tend to form oxide nanoparticles, ZnO and CuO, due to their higher susceptibility to oxidation. Compared to ZnO and CuO nanoparticles, Ag nanoparticles exhibit faster formation kinetics, narrower size distribution, and improved colloidal stability. In terms of applications, silver nanoparticles show pronounced catalytic and antimicrobial activity, while ZnO and CuO nanoparticles demonstrate significant potential in photocatalysis, environmental protection, and the development of functional materials. This comparative overview provides deeper insight into the advantages and limitations of green synthesis for different metal nanoparticles and supports their targeted application.

Keywords: green synthesis, Ag nanoparticles, ZnO nanoparticles, CuO nanoparticles, comparative analysis

---

1. INTRODUCTION

Nanotechnology represents one of the most dynamic fields of modern science, with a wide range of applications in medicine, pharmacy, catalysis, energy, and environmental protection. Due to their high surface-to-volume ratio and unique optical, electronic, and chemical properties, metal nanoparticles exhibit significantly different characteristics compared to their bulk counterparts. Silver, zinc oxide, and copper oxide nanoparticles

are of particular interest because of their pronounced antimicrobial, catalytic, and photocatalytic properties [1–2].

Conventional methods for the synthesis of metal nanoparticles, including chemical and physical approaches, often require the use of toxic reducing agents, organic solvents, and high energy inputs. Such procedures may lead to the formation of harmful by-products and represent a potential risk to the environment and human health. For this reason, in recent years there has been increasing interest in the development of sustainable and environmentally friendly synthesis methods [3].

Green synthesis of nanoparticles is based on the principles of green chemistry and involves the use of biological systems such as plants, microorganisms, and biomolecules for the reduction of metal ions and stabilization of the formed nanoparticles. Plant extracts are particularly attractive due to their simple preparation, availability, low cost, and the presence of various bioactive compounds (phenols, flavonoids, alkaloids, proteins, and terpenoids) that can act as both reducing and stabilizing agents [3].

Mechanism of nanoparticle formation in green synthesis depends on the nature of the metal and the chemical characteristics of the biomolecules present in the plant extract. In the case of silver, a direct reduction of Ag^{+} ions to elemental Ag^{0} occurs, leading to the formation of stable colloidal systems with a pronounced surface plasmon resonance (SPR) maximum. In contrast, zinc and copper show a higher tendency toward oxidation; therefore, oxide nanoparticles such as ZnO and CuO are most commonly formed during the synthesis process. The properties of these nanoparticles are largely determined by their semiconducting nature and the width of their band gap [4].

In this study, the extract of *Agrimonia eupatoria* L. was used for the green synthesis of all nanoparticles (silver, ZnO, and CuO). *Agrimonia eupatoria* L. (family Rosaceae), also known as agrimony, is used as a raw material for the extraction of biologically active components or for the production of pharmaceuticals in the pharmaceutical industry. This plant exhibits anti-inflammatory, neuroprotective, antidiabetic, hepatoprotective, and anticancer properties, in addition to pronounced antioxidant and antibacterial activities [5].

Accordingly, the aim of this study is a comparative analysis of the green synthesis of silver, zinc oxide, and copper oxide nanoparticles with respect to their formation mechanisms, process kinetics, morphological characteristics, colloidal stability, and potential application fields, based on the authors' experimental results as well as relevant literature data.

2. EXPERIMENTAL

All precursor salts used for the green synthesis—silver nitrate ($AgNO_3$), zinc acetate ($Zn(CH_3COO)_2{\cdot}2\ H_20$), and copper sulfate ($CuSO_4\ {\cdot}5\ H_20$)—were purchased from Sigma-Aldrich. Data were analyzed using OriginPro 2019b – 64 bit, and the synthesis of all nanoparticles (Ag, ZnO, and CuO) was monitored with a PerkinElmer Lambda 365 spectrophotometer in the 200–800 nm wavelength range. All synthesized nanoparticles (Ag, ZnO, and CuO) were characterized by TEM using an FEI Talos F200X microscope and by FTIR spectroscopy with a PerkinElmer Spectrum One FT-IR to analyze their microstructure and functional groups. A magnetic stirrer (MAGE 12/17) and a laboratory

microcentrifuge (Scilogekj DM0412) were used for nanoparticle synthesis and separation.

2.1. Preparation of plant extracts

The previously described method was used for the preparation of the aqueous plant extract [5]. Dried and powdered plant material (60 g) was soaked in 800 mL of distilled water, and the maceration process was repeated three times at room temperature. Fresh solvent was used every 24 h, and the samples were filtered through filter paper. The obtained filtrates were then concentrated using a rotary evaporator at 40 °C. The dry aqueous extract was stored at 4 °C until further use [6].

2.2. Synthesis of silver nanoparticles

Silver nitrate ($AgNO_3$) was used for the synthesis of Ag nanoparticles. The aqueous plant extract was employed as a reducing and stabilizing agent. The procedure was carried out under control using a magnetic stirrer. The optimized synthesis conditions were determined by varying parameters such as the concentration of starting components, pH, and temperature. The formation of AgNPs was monitored by UV–Vis spectrophotometry and visual color change (from light yellow to dark brown) to determine the optimal conditions. Using the aqueous plant extract, the highest yield of AgNPs was obtained after 3 h of reaction, at 25 °C, pH 6, with 5 mM $AgNO_3$ and 1% plant extract. After synthesis, the suspension was centrifuged using a laboratory microcentrifuge for 20 minutes at 4500 rpm. The remaining material was centrifuged once more and then resuspended in demineralized water. The precipitated nanoparticles were dried in a hot air oven at 40 °C and stored at 4 °C. Dana [6,7,8].

2.3. Synthesis of ZnO nanoparticles

The aqueous extract of *Agrimonia eupatoria* L. was used as a reducing and stabilizing agent in the synthesis of ZnO nanoparticles. The extract (20 mL, 1%) was prepared, filtered if necessary, and heated to 50 °C under constant stirring. A solution of zinc acetate (0.55044 g in 30 mL of distilled water, 0.1 M) was added dropwise to the extract under continuous stirring. The pH of the reaction mixture was adjusted to 12–13 using 1 M NaOH. The total reaction volume was 50 mL. After standing overnight, the resulting suspension was centrifuged (4500 rpm, 2 × 20 min), washed several times with distilled water and once with ethanol, and then dried overnight at up to 200 °C to obtain ZnO nanoparticles. The formation of ZnO nanoparticles was confirmed by UV–Vis spectroscopy, with a characteristic absorption peak at 365 nm.

2.4. Synthesis of CuO nanoparticles

The aqueous extract of *Melissa officinalis* was used as a reducing and stabilizing agent in the synthesis of CuO nanoparticles. A 5 mM solution of $CuSO_4 \cdot 5H_2O$ (0.062 g in 50 mL of distilled water) was prepared, and the aqueous plant extract (1 g/L) was obtained by dissolving the appropriate amount of dried plant material in distilled water,

followed by brief ultrasonic treatment and filtration. The extract was added dropwise to the copper(II) sulfate solution under constant stirring, and the pH of the reaction mixture was adjusted to approximately 8 using 0.1 M NaOH. The formation of CuO nanoparticles was monitored by UV–Vis spectroscopy, with a color change from blue through green to brown. For the specific batch, the resulting suspension was centrifuged at 4,000 rpm for 20 minutes twice in distilled water and once in ethanol, and then left to dry at room temperature in the same cuvettes, yielding CuO nanoparticles.

3. RESULTS AND DISCUSSION

In this section, the characterization of the synthesized silver (Ag), zinc oxide (ZnO), and copper oxide (CuO) nanoparticles is presented using three complementary experimental techniques: transmission electron microscopy (TEM), Fourier-transform infrared spectroscopy (FTIR), and UV–Vis spectrophotometry. This approach allows a comprehensive analysis of their morphology, chemical composition, and optical properties.

3.1. Transmission electron microscopy (TEM) characterization of AgNPs, ZnONPs and CuONPs

The TEM analysis reveals distinct differences in morphology and particle size distribution among the synthesized nanoparticles (Fig. 1.).

Silver nanoparticles (AgNPs) exhibit predominantly spherical morphology with relatively uniform size distribution, indicating efficient reduction and stabilization by plant biomolecules, in agreement with previously reported results [5].

In contrast, ZnONPs show more irregular shapes and a broader size distribution, which may be attributed to their formation through intermediate hydroxide species and subsequent conversion to oxide structures.

CuONPs are characterized by pronounced agglomeration and less uniform morphology, with a wider size distribution compared to AgNPs, as also reported in the literature [9]. This behavior can be explained by the higher tendency of copper to undergo oxidation and form oxide phases, as well as weaker stabilization by biomolecules.

Overall, the observed differences confirm that the nature of the metal precursor plays a crucial role in determining nanoparticle morphology, size distribution, and degree of aggregation during green synthesis.

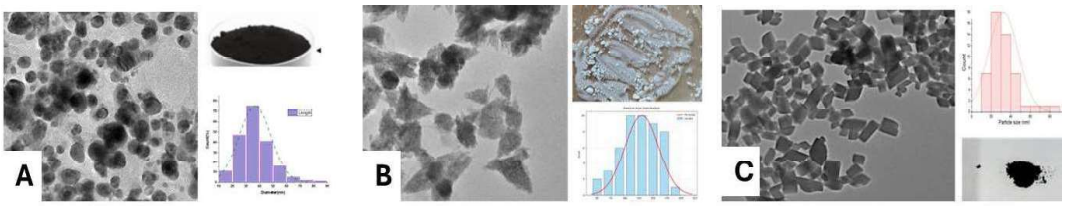


Fig. 1. TEM micrographs and corresponding particle size distribution histograms of green-synthesized nanoparticles: (A) AgNPs obtained using *Agrimonia eupatoria* extract [5], (B) ZnONPs and (C) CuONPs synthesized using plant extract [9].

3.2. FTIR analysis of AgNPs, ZnONPs and CuONPs

FTIR analysis was employed to identify the functional groups of biomolecules involved in the reduction and stabilization of nanoparticles. The spectra of plant extracts exhibit characteristic absorption bands corresponding to O–H, C=O, and C–O vibrations, indicating the presence of phenols, flavonoids, and other bioactive compounds.

In the spectra of AgNPs and ZnONPs, shifts and changes in the intensity of these bands are observed compared to the plant extract, confirming their involvement in the synthesis and stabilization processes. These changes are more pronounced in the case of AgNPs, suggesting stronger interactions between biomolecules and the nanoparticle surface.

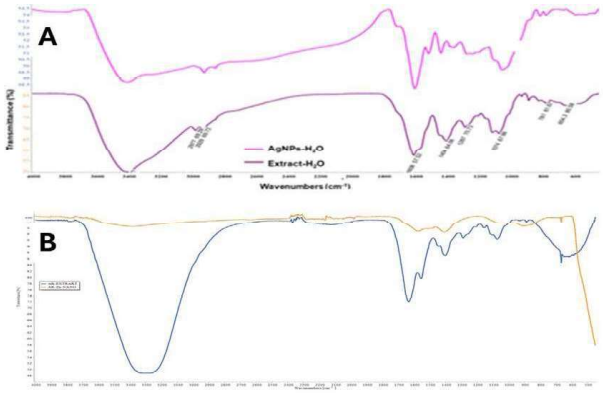


Fig. 2. FTIR spectra of (A) *Agrimonia eupatoria* extracts and corresponding AgNPs [5], and (B) *Agrimonia eupatoria* extracts and corresponding ZnONPs.

3.3. UV-vis analysis of AgNPs, ZnONPs i CuONPs

UV–Vis spectrophotometry was used to monitor the formation and optical properties of the synthesized nanoparticles (Fig. 3). Changes in the absorption spectra, as well as visible color changes of the reaction mixtures, provide important information about the reaction progress and nanoparticle formation.

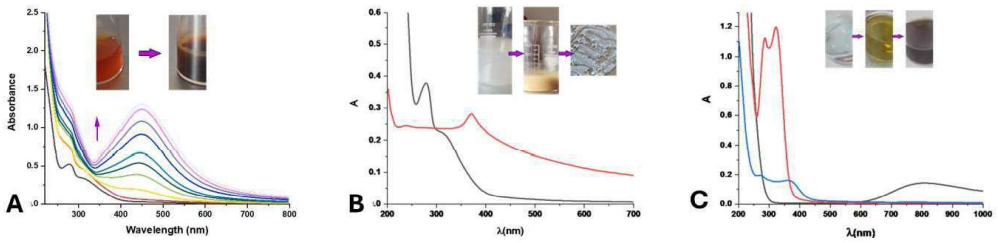


Fig. 3. UV–Vis absorption spectra and corresponding color changes during the green synthesis of (a) AgNPs, (b) ZnONPs, and (c) CuONPs.

In the case of silver nanoparticles, a characteristic surface plasmon resonance (SPR) band is observed in the region of 400–450 nm, whose increasing intensity over time indicates nanoparticle formation and growth, in agreement with previously reported results [5]. A simultaneous color change from light yellow to dark brown further confirms the formation of AgNPs.

For ZnO nanoparticles, the spectrum shows a distinct absorption maximum around 360–370 nm, which is typical for ZnO and associated with its semiconducting properties. The color change is less pronounced compared to silver nanoparticles, which is consistent with the formation mechanism of oxide nanoparticles.

In the case of CuO nanoparticles, no distinct SPR peak is observed; instead, a broad absorption band appears in the UV region, which is characteristic of oxide systems. The color change from blue through green to brown indicates the transformation of Cu(II) ions and the formation of CuO nanoparticles.

These results confirm that UV–Vis spectroscopy is a reliable method for monitoring the green synthesis process and distinguishing between metallic and oxide nanoparticles.

3.4. Comparative analysis of synthesized nanoparticles

A comparative summary of the key characteristics of green-synthesized Ag, ZnO, and CuO nanoparticles is presented in Table 1.

As shown, silver nanoparticles are formed via direct reduction under mild conditions and exhibit faster formation kinetics and higher colloidal stability. In contrast, zinc and copper predominantly form oxide nanoparticles through hydroxide intermediates under alkaline conditions, resulting in moderate formation rates and lower stability. These differences highlight the strong influence of metal nature on the synthesis pathway and the resulting nanoparticle properties.

Table 1. Key differences in green synthesis and properties of Ag, ZnO and CuO nanoparticles

Property	AgNPs	ZnONPs	CuONPs
Dominant phase	Ag^0 (metallic)	ZnO (oxide)	CuO (oxide)
Formation mechanism	Direct	Hydroxide →	Hydroxide →

	reduction	oxide	oxide
Reaction conditions	Mild (pH ~6)	Strongly alkaline (pH 12–13)	Moderately alkaline (pH ~8)
Formation rate	Fast	Moderate	Moderate
UV–Vis feature	SPR (~400–450 nm)	Absorption edge (~365 nm)	Broad absorption
Stability	High	Mode rate	Lower
Key applications	Antimicrobial, catalytic	Photocatalysis, sensors, environmental remediation	Catalysis, antimicrobial, environmental applications

4. CONCLUSION

The obtained results indicate significant differences in the formation mechanisms, morphology, and stability of nanoparticles depending on the nature of the metal precursor. Silver nanoparticles are formed via direct reduction of Ag^+ ions to elemental Ag^0, enabling faster formation kinetics, higher uniformity, and improved colloidal stability. In contrast, zinc and copper tend to form oxide nanoparticles (ZnO and CuO) through hydroxide intermediates, resulting in slower formation rates and greater system heterogeneity.

TEM and FTIR analyses confirm the crucial role of biomolecules from plant extracts in both the reduction and stabilization processes, with more pronounced interactions observed in the case of silver nanoparticles.

Overall, the results demonstrate that the choice of metal precursors strongly influences the green synthesis pathway and the final properties of the obtained nanoparticles, enabling their targeted application in various fields.

In terms of potential applications, silver nanoparticles exhibit pronounced antimicrobial and catalytic activity, whereas ZnO nanoparticles show significant potential in photocatalysis and environmental remediation. CuO nanoparticles, on the other hand, demonstrate promising properties in catalytic processes and environmental applications.

Acknowledgments: This research is funded by the Ministry of Education and Ministry of Science, Technological Development and Innovation, Republic of Serbia, Grants: No. 451-03-33/2026-03/200378.

5. LITERATURE

[1] Rai, M., Yadav, A. & Gade, A. (2009), "Silver nanoparticles as a new generation of antimicrobials", *Biotechnology Advances*, 27, 76–83.

[2] Maleki Dizaj, S., Lotfipour, F., Barzegar-Jalali, M., Zarrintan, M. H. & Adibkia, K. (2014), "Antimicrobial activity of the metals and metal oxide nanoparticles", *Materials Science and Engineering: C*, 44, 278–284.

[3] Singh, J., Dutta, T., Kim, K.-H., Rawat, M., Samddar, P. & Kumar, P. (2018), "Green synthesis of metals and their oxide nanoparticles: Applications for environmental remediation", *Journal of Nanobiotechnology*, 16, 84.

[4] Husen, A. & Siddiqi, K. S. (eds.) (2023), *Advances in smart nanomaterials and their applications*, Amsterdam, The Netherlands: Elsevier.

[5] Muruzović, M. Ž., Mladenović, K. G., Stefanović, O. D., Vasić, S. M. & Čomić, L. R. (2023), *Antimicrobial, antioxidant and antibiofilm activity of extracts of Agrimonia eupatoria L.Journal of Food and Drug Analysis*, 24, 539–547.

[6] Marković, K., Kesić, A., Novaković, M., Grujović, M., Simijonović, D., Avdović, E. H., Matić, S., Paunović, M., Milutinović, M., Nikodijević, D., Stefanović, O. & Marković, Z. (2024), "Biosynthesis and characterization of silver nanoparticles synthesized using extracts of *Agrimonia eupatoria* L. and in vitro and in vivo studies of potential medicinal applications", *RSC Advances*, 14, 4591–4606.

[7] Kesić A. S., Marković K. G., Grujović M. Ž., Marković Z. S. (2023). Characterization of silver nanoparticles synthesized using plant extracts. *Materials Proceedings*. **14**: 1–5.

[8] Marković G. K., Grujović M. Ž., Kesić A. S., Marković Z. S. (2022). Optimization of silver nanoparticle synthesis using plant extracts. Published in *8th Edition of Our Series of International Electronic Conferences on Medicinal Chemistry (ECMC 2022)*. Basel, Switzerland: MDPI.

[9] Ali, S. G., Haseen, U., Jalal, M., Khan, R. A., Alsalme, A., Ahmad, H. & Khan, H. M. (2023), "*Green synthesis of copper oxide nanoparticles from the leaves of Aegle marmelos and their antimicrobial activity and photocatalytic activities*", Molecules, **28**, 7499.

Uporedna analiza zelene sinteze nanočestica srebra, cinka i bakra korišćenjem biljnih ekstrakata

Ana Kesić*, Katarina Marković, Mirjana Grujović,
Jelena Katanić Stanković

Univerzitet u Kragujevcu, Institut za informacione tehnologije Kragujevac, Jovana Cvijića bb, 34000 Kragujevac, Srbija

akesic@uni.kg.ac.rs

Uvod

- ✓ **Nanotehnologija –** jedna od najbrže razvijajućih oblasti savremene nauke

- ✓ Nanočestice su materijali dimenzija od **1 do 100 nm.**

- ✓ **Primena metalnih nanočestica** u: medicini, farmaciji, katalizi, energetici, zaštiti životne sredine…

- ✓ **Specifična svojstva** nanočestica:
  - veliki odnos površine i zapremine
  - jedinstvena optička i elektronska svojstva
  - povećana hemijska reaktivnost

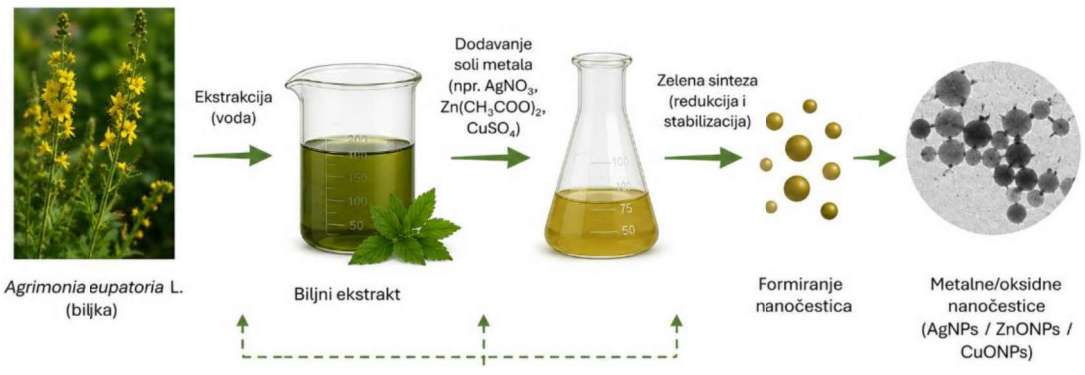
- ✓ Metalne nanočestice u ovom istraživanju:
  - **AgNPs** $Ag^{+} \rightarrow Ag^{0}$ (metalne nanočestice srebra)
  - **ZnONPs** - formiranje oksidnih nanočestica
  - **CuONPs** - formiranje oksidnih nanočestica

Sinteza nanočestica

- ✓ **Klasične metode sinteze**:
  - upotreba toksičnih hemikalija
  - velika potrošnja energije
  - nastanak štetnih nusproizvoda

- ✓ **Zelena sinteza nanočestica**:
  - **ekološki prihvatljiv** pristup
  - zasnovana na principima **zelene hemije**
  - upotreba **biljnih ekstrakata** kao redukcionih i stabilizacionih agenasa

- ✓ Prednosti upotrebe **biljnih ekstrakata** u zelenoj sintezi nanočestica:
  - dostupnost i niska cena
  - jednostavna priprema
  - prisustvo **bioaktivnih komponenti** (fenoli, flavonoidi, tanini)



Cilj rada

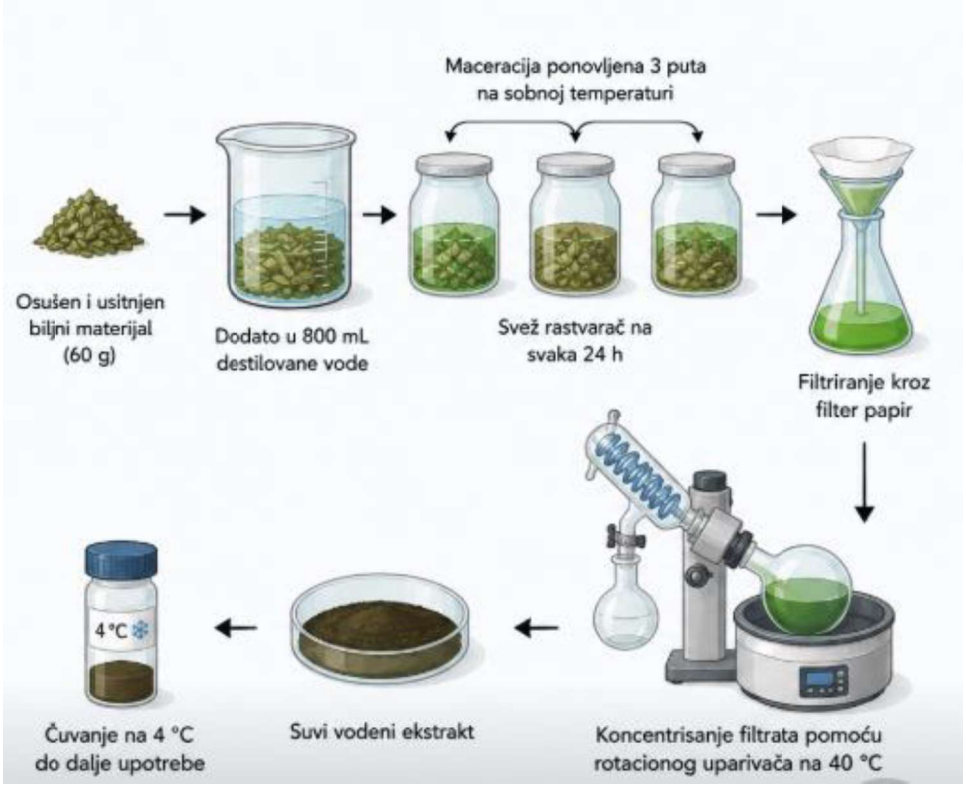
- ✓ **Priprema** nanočestica zelenom sintezom uz pomoć biljke
- ✓ **Mehanizam formiranja i kinetika**
- ✓ **Morfologija, stabilnost i primena**
- ✓ Komparativna analiza **AgNPs, ZnONPs i CuONPs**





Priprema biljnog ekstrakta

- ✓ ***Agrimonia eupatoria* L.** pripada porodici ***Rosaceae*.**
- ✓ *A. eupatoria* se u narodnoj medicini koristi za lečenje **inflamatornih i digestivnih bolesti**.
- ✓ Pokazuje značajnu **antioksidativnu aktivnost** i poseduje dobru **redukcionu moć**.



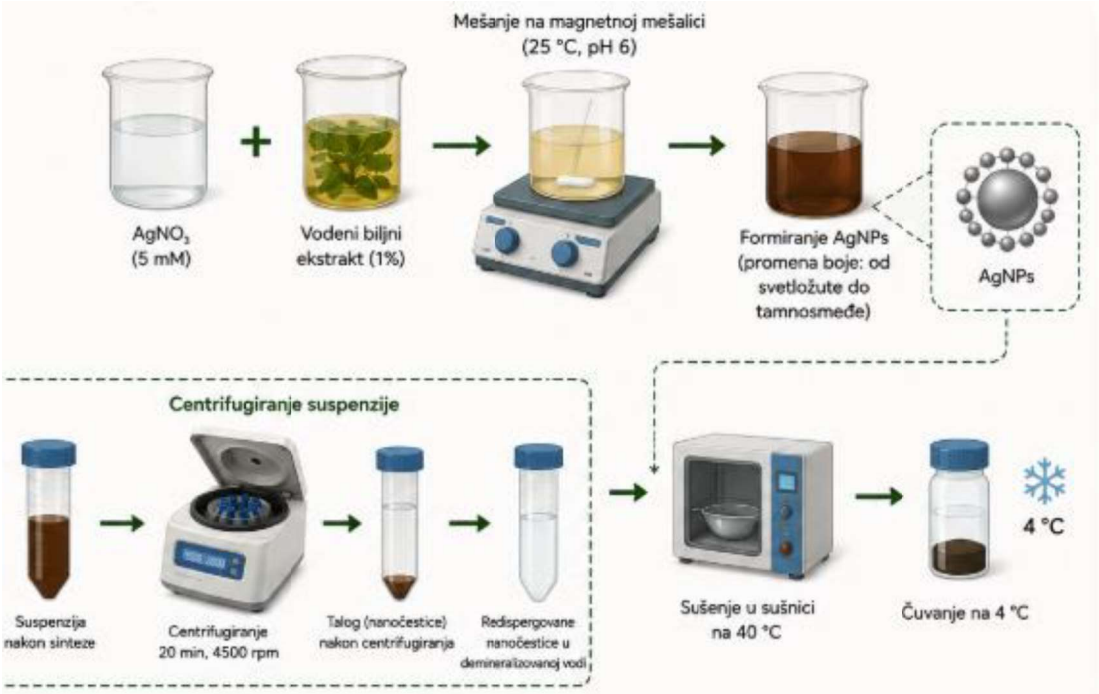
- ✓ **Osušen i usitnjen biljni materijal** (60 g) potopljen je u 800 mL destilovane vode.
- ✓ Proces **maceracije** ponovljen je tri puta na sobnoj temperaturi.
- ✓ Svež rastvarač korišćen je na svaka **24 h**, a uzorci su filtrirani kroz filter papir.
- ✓ Dobijeni filtrati koncentrovani su pomoću **rotacionog uparivača** na 40 °C.
- ✓ Suvi vodeni ekstrakt čuvan je na **4 °C**.

[1] Muruzovic M et al. Journal of Food and Drug Analysis, 2016, 24: 539–547

Sinteza Ag nanočestica

- ✓ Za sintezu srebrnih nanočestica korišćen je **srebro-nitrat** ($AgNO_3$).
- ✓ Vodeni biljni ekstrakt korišćen je kao **redukujući i stabilizacioni agens**.
- ✓ Sinteza je izvođena uz kontrolisano mešanje na **magnetnoj mešalici**.
- ✓ **Optimizacija sinteze** sprovedena je promenom sledećih parametara: koncentracija početnih komponenti, pH vrednost, temperatura
- ✓ **Formiranje AgNPs** praćeno je:
  - – UV–Vis spektrofotometrijom
  - – vizuelnom promenom boje (od svetložute do tamnosmeđe).
- ✓ Nakon sinteze, suspenzija je **centrifugirana 20 min pri 4500 rpm**.
- ✓ Istaložene nanočestice sušene su u **sušnici na 40 °C** i čuvane na **4 °C** [6–8].

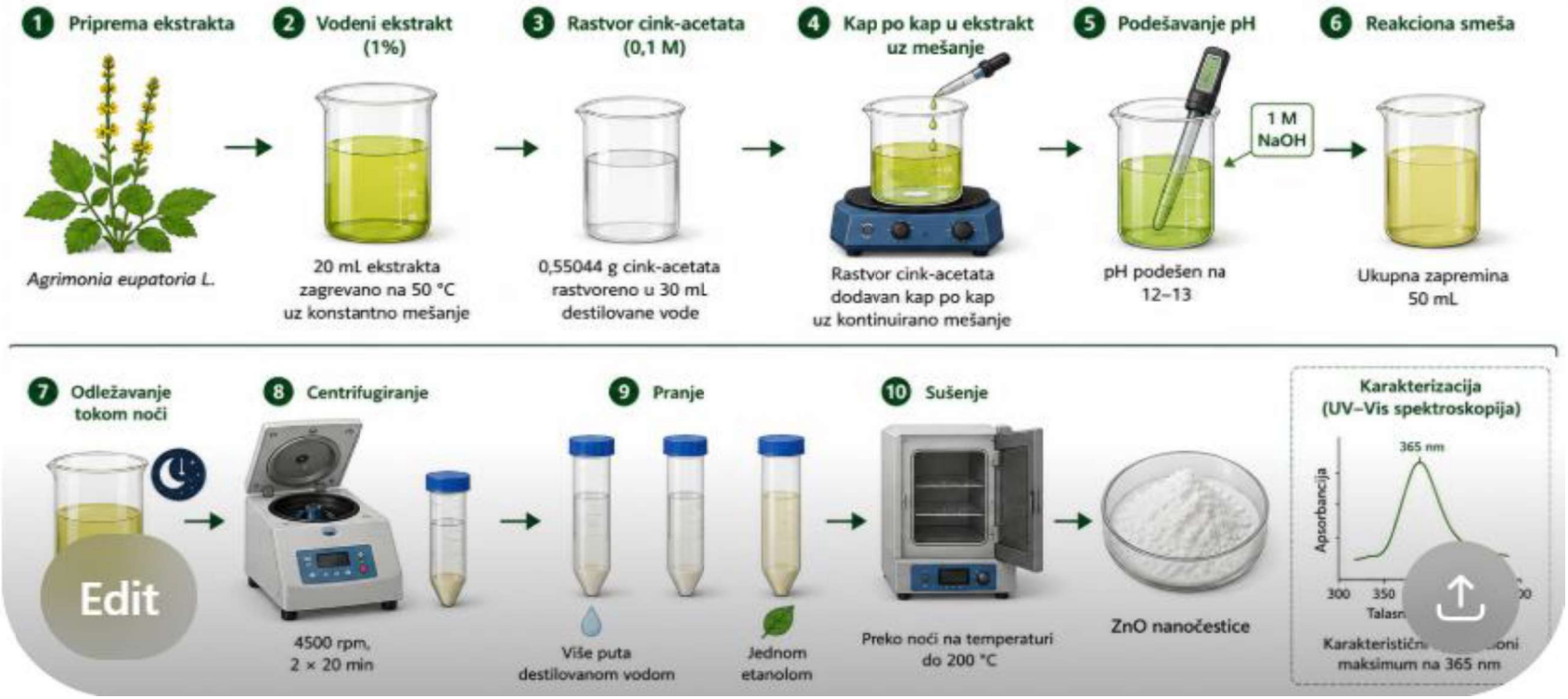




Optimalni uslovi sinteze bili su:
vreme reakcije: 3 h.
temperatura: 25 °C,
pH: 6,
koncentracija $AgNO_3$:5 mM,
koncentracija biljnog ekstrakta:1%

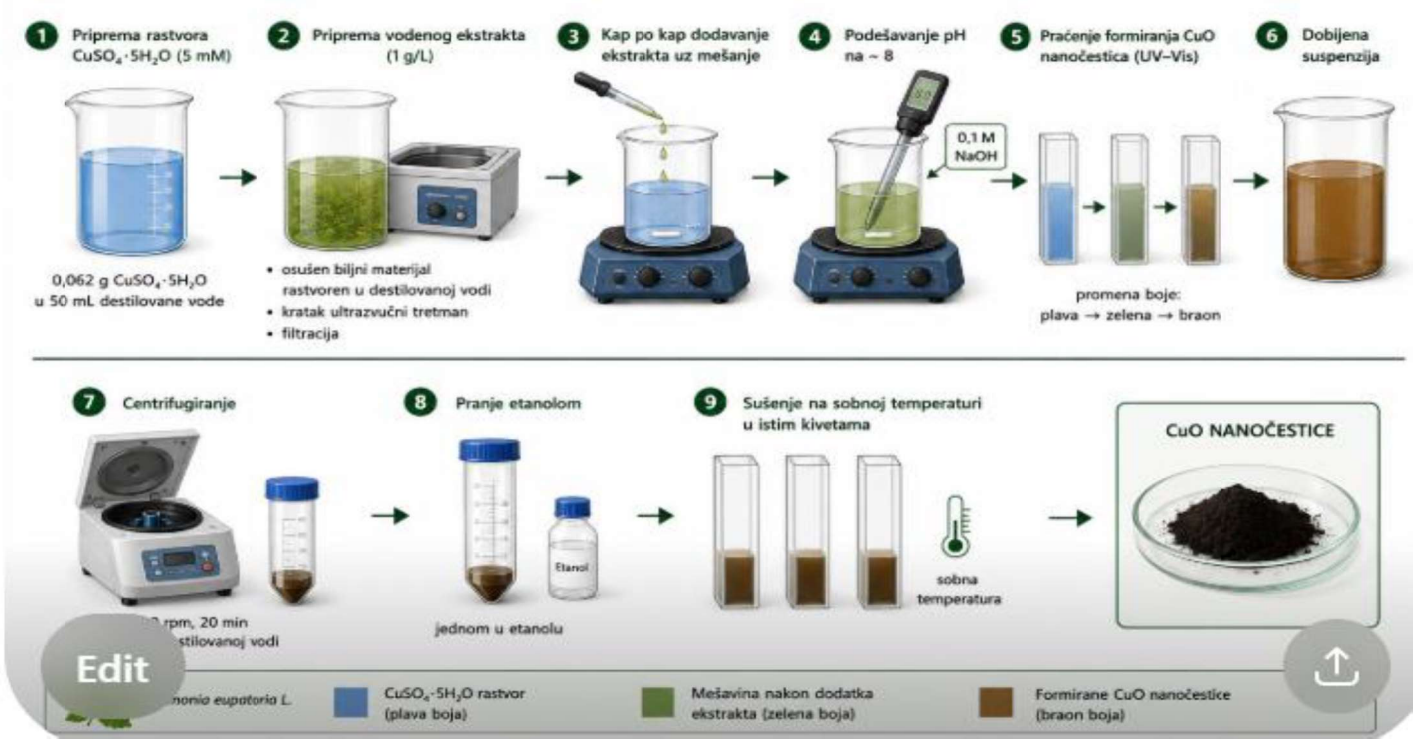
1. Marković K et al. RSC Advances, 2024, 14: 4591–4606
2. Kesić AS et al. Materials Proceedings, 2023, 14: 1–5
3. Marković GK et al. 8th International Electronic Conference on Medicinal Chemistry (ECMC), MDPI, 2022

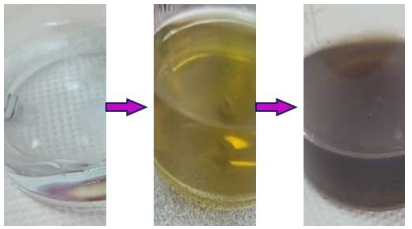
Sinteza ZnO nanočestica



- ✓ Pripremljen je **1% vodeni ekstrakt biljke.**
- ✓ **Rastvor cink-acetata** (0,1 M) dodat je kap po kap u rastvor ekstrakta uz kontinuirano mešanje.
- ✓ **pH** reakcione smeše je podešen na **12–13** dodatkom 1 M NaOH.
- ✓ Nakon odležavanja tokom noći, dobijena suspenzija se **centrifugira** na 4500 rpm (2 × 20 min).
- ✓ Nanočestice su sušene preko noći na temperaturi do **200 °C** radi dobijanja ZnO nanočestica.
- ✓ Formiranje ZnO nanočestica potvrđeno je **UV–Vis** spektroskopijom, sa karakterističnim apsorpcionim maksimumom na **365 nm.**

Sinteza CuO nanočestica

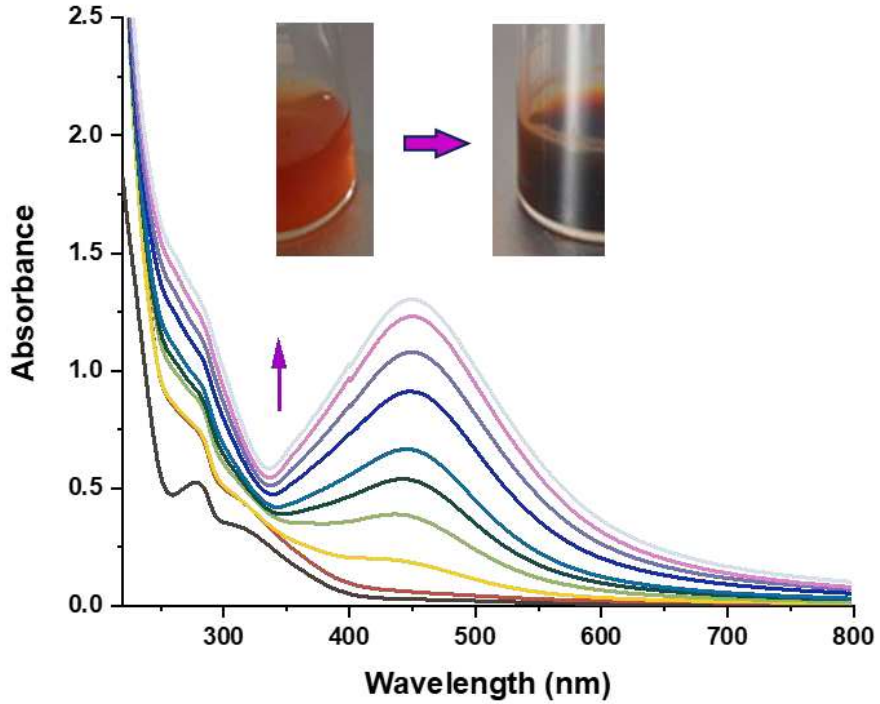




- ✓ Pripremljen je 5 mM rastvor **$CuSO_4 \cdot 5H_2O$.**
- ✓ **Vodeni biljni ekstrakt** (1 g/L) pripremljen je rastvaranjem osušenog biljnog materijala u destilovanoj vodi kratkim ultrazvučnim tretmanom i filtracijom.
- ✓ Biljni ekstrakt dodat je **kap po kap** u rastvor bakar(II)-sulfata uz konstantno mešanje.
- ✓ pH reakcione smeše podešen je na približno **8** dodatkom 0,1 M NaOH.
- ✓ Formiranje CuO nanočestica praćeno je **UV–Vis spektroskopijom** i promenom boje: **– plava → zelena → braon**.
- ✓ Dobijena suspenzija je **centrifugirana**: 3 × 20 min pri 4000 rpm dva puta u destilovanoj vodi i jednom u etanolu.
- ✓ Nakon centrifugiranja, uzorci su sušeni na **sobnoj temperaturi** .

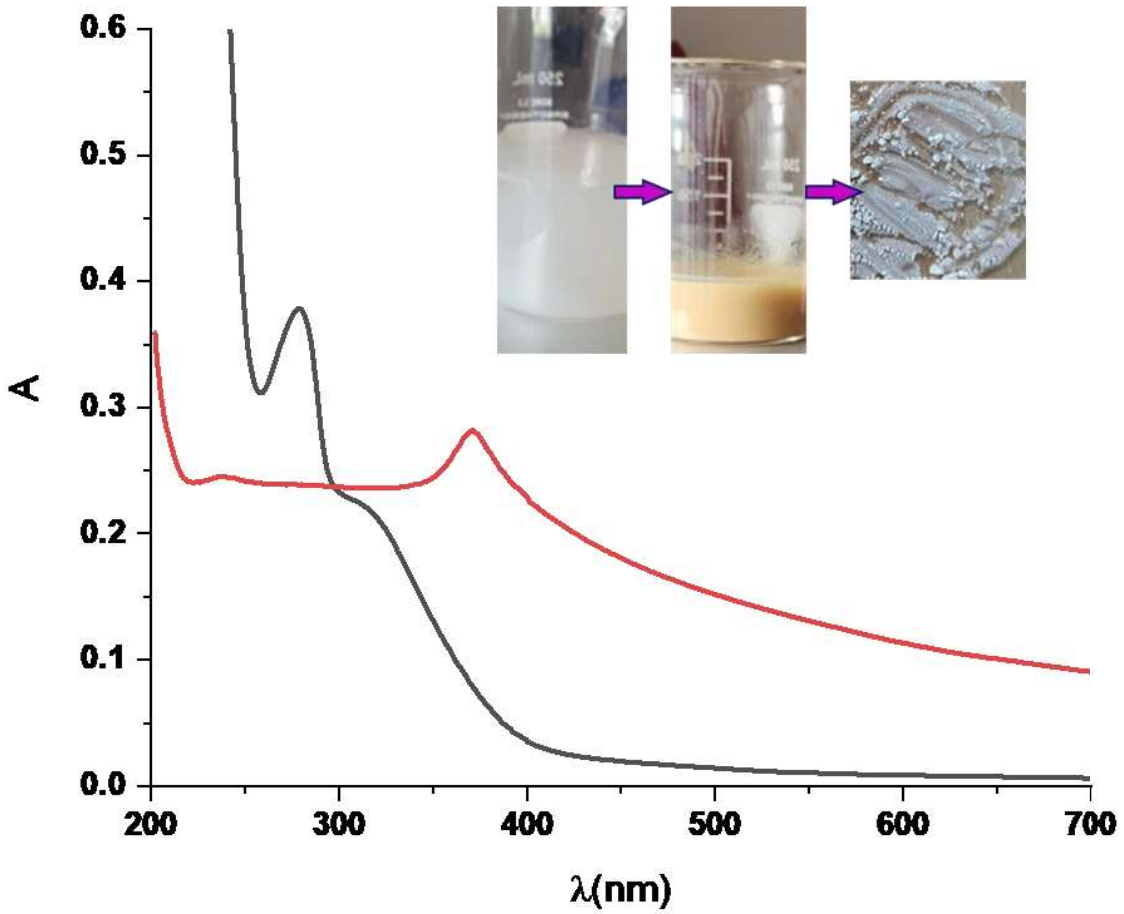
UV–Vis analiza sintetisanih nanočestica

- ✓ UV–Vis spektrofotometrija korišćena je za **praćenje formiranja i optičkih svojstava sintetisanih nanočestica.**
- ✓ Promene u apsorpcionim spektrima i promena boje reakcione smeše pružaju informacije **o toku reakcije i formiranju nanočestica.**
- ✓ Praćenje **procesa zelene sinteze** nanočestica.



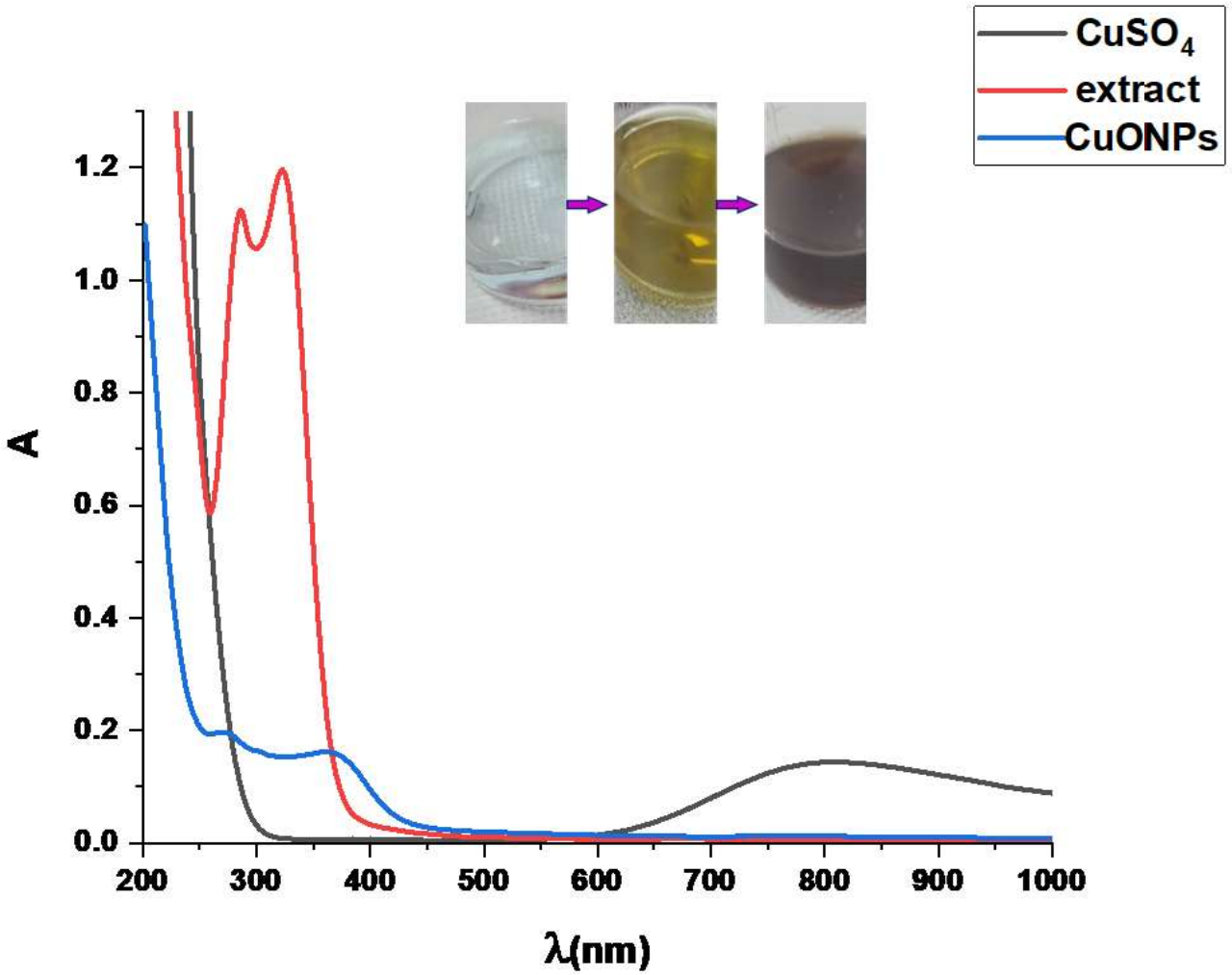
UV–Vis apsorpcioni spektri i odgovarajuće promene boje tokom zelene sinteze: AgNPs

- ✓ Uočen je karakterističan maksimum u oblasti **400–450 nm**.
- ✓ **Povećanje intenziteta pika tokom vremena** ukazuje na formiranje i rast nanočestica.
- ✓ Promena boje reakcione smeše: **svetložuta → tamnosmeđa → crna**



UV–Vis apsorpcioni spektri i odgovarajuće promene boje tokom zelene sinteze: ZnONPs

- ✓ Prisutan je karakterističan apsorpcioni maksimum na **360–370 nm**.
- ✓ **Promena boje je** manje izražena u odnosu na AgNPs.

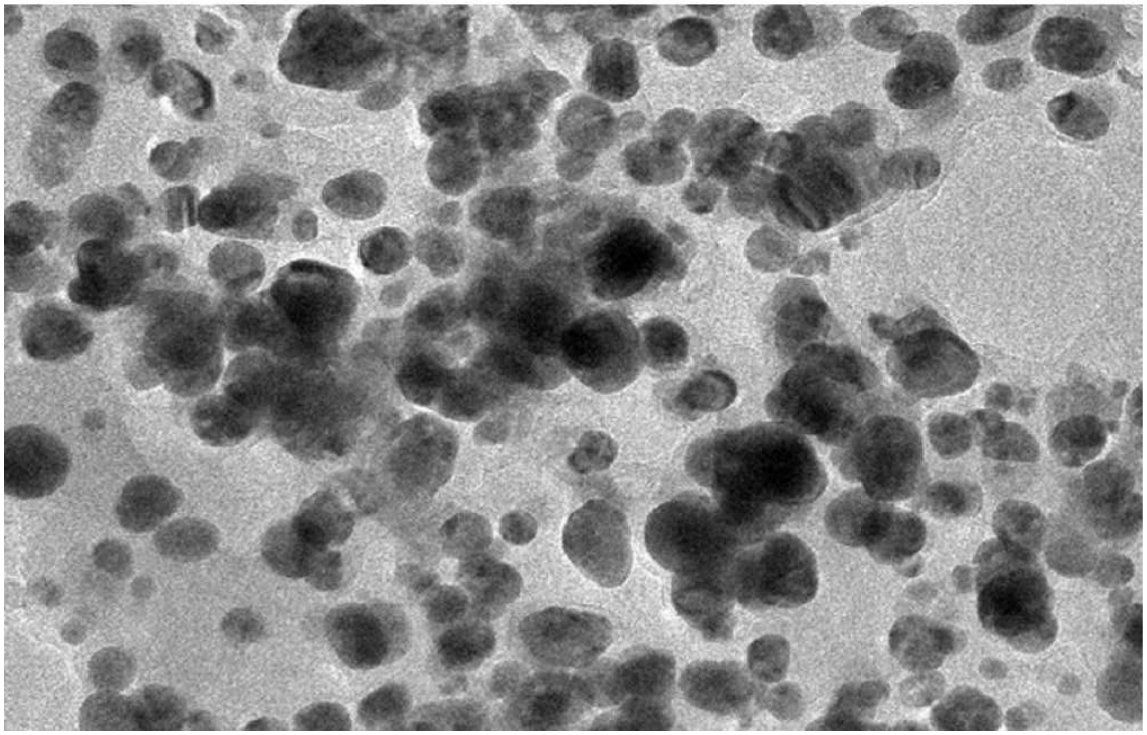


UV–Vis apsorpcioni spektri i odgovarajuće promene boje tokom zelene sinteze: CuONPs

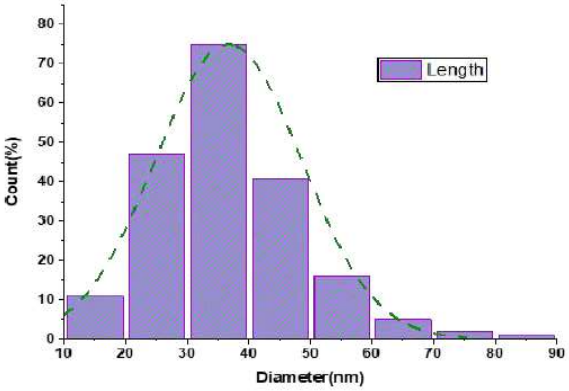
- ✓ **Nije uočen karakterističan maksimum.**
- ✓ Registrovana je **široka apsorpciona traka** u UV oblasti, tipična za oksidne sisteme.
- ✓ Promena boje reakcione smeše: **– plava → zelena → braon.**

TEM analiza nanočestica

- ✓ **TEM analiza** pokazala je značajne **razlike** u morfologiji i raspodeli veličine između sintetisanih nanočestica.

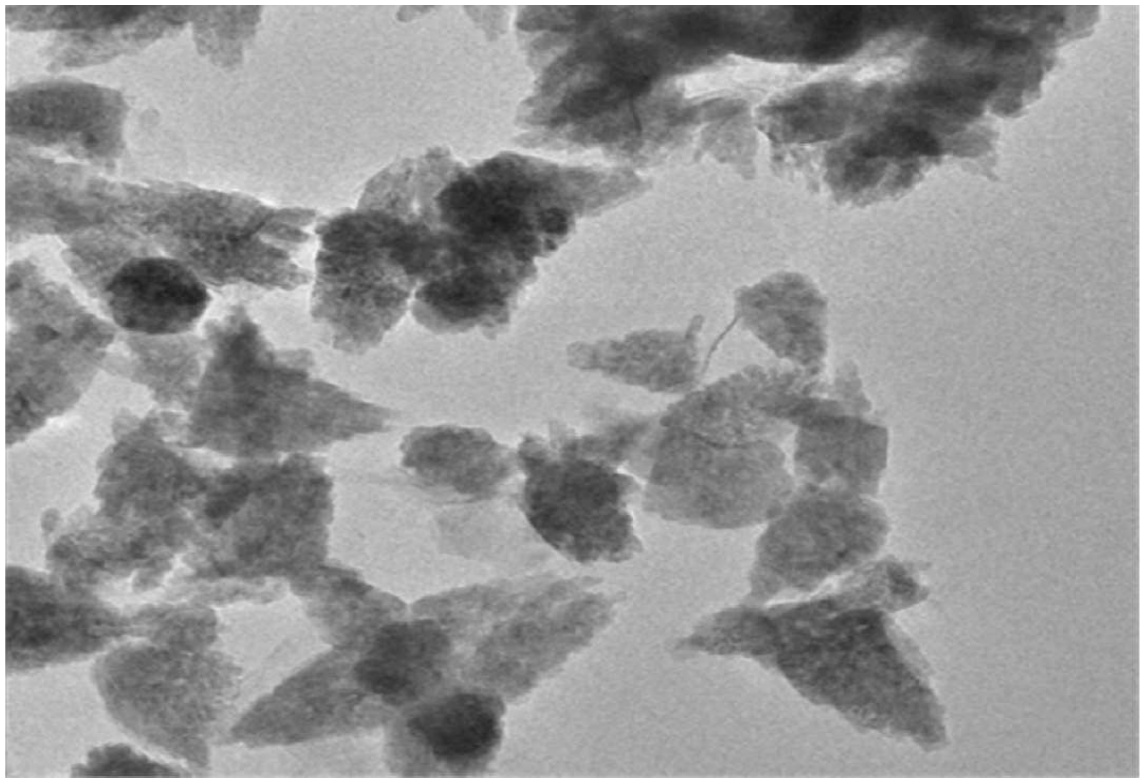




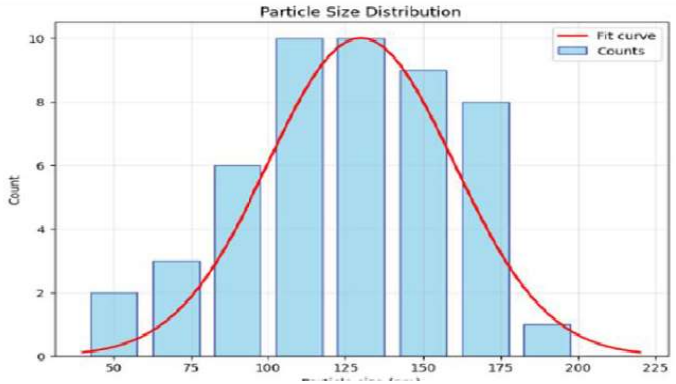


TEM mikrografije i odgovarajući histogrami raspodele veličine AgNPs

- ✓ **AgNPs** imaju pretežno **sferičnu** morfologiju i relativno **usku raspodelu veličine.**
- ✓ Efikasna **redukcija i stabilizacija** pomoću biljnih biomolekula.

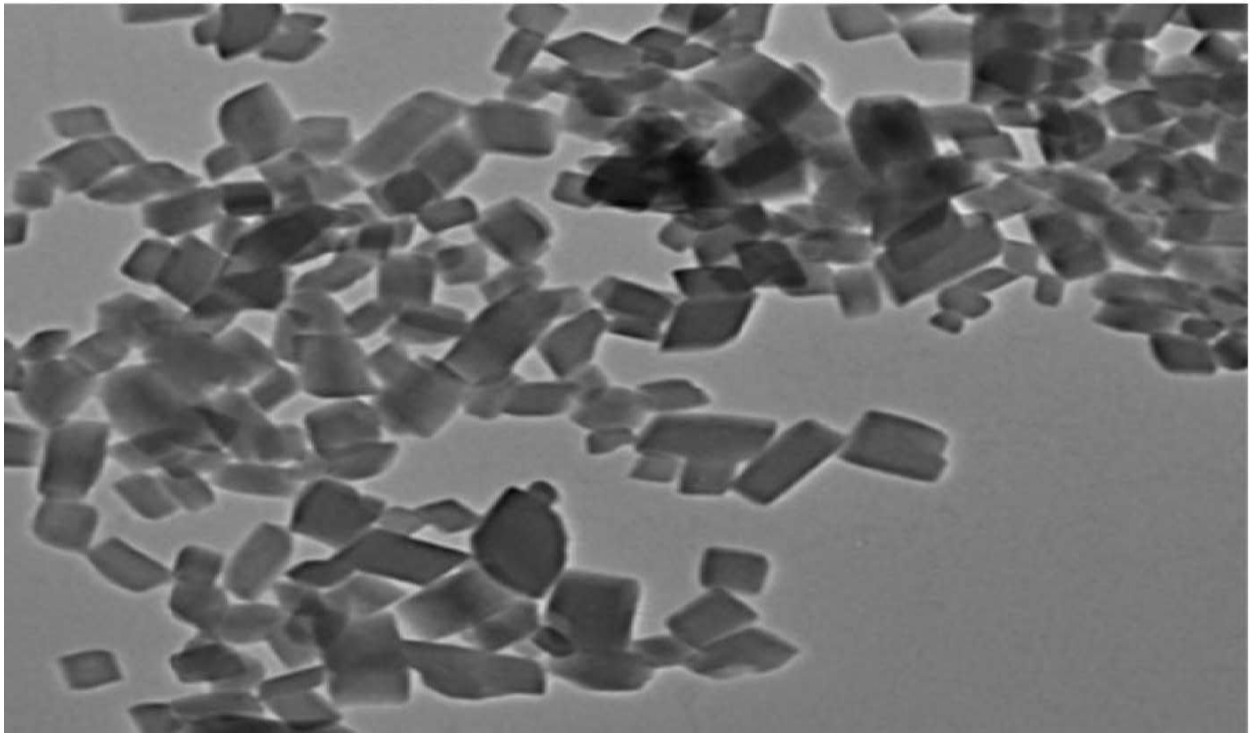


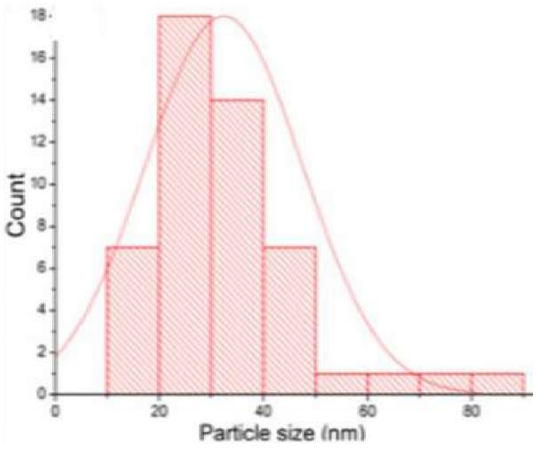


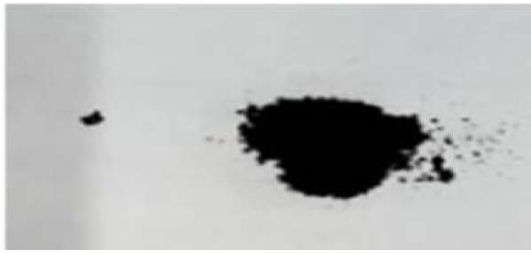


TEM mikrografije i odgovarajući histogrami raspodele veličine ZnONPs

- ✓ **ZnONPs** pokazuju **nepravilniji oblik i širu raspodelu veličina** u odnosu na AgNPs.
- ✓ Formiranje preko **hidroksidnih intermedijera** i naknadna konverzija u oksidne strukture.





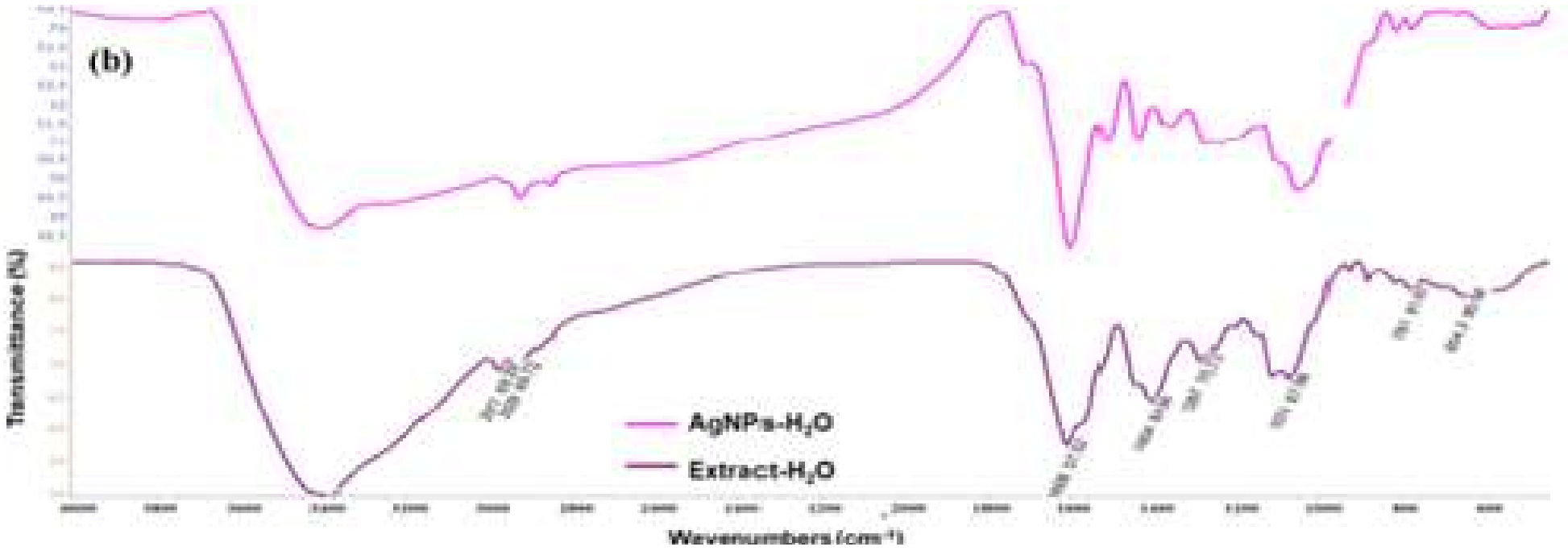


TEM mikrografije i odgovarajući histogrami raspodele veličine CuONPs

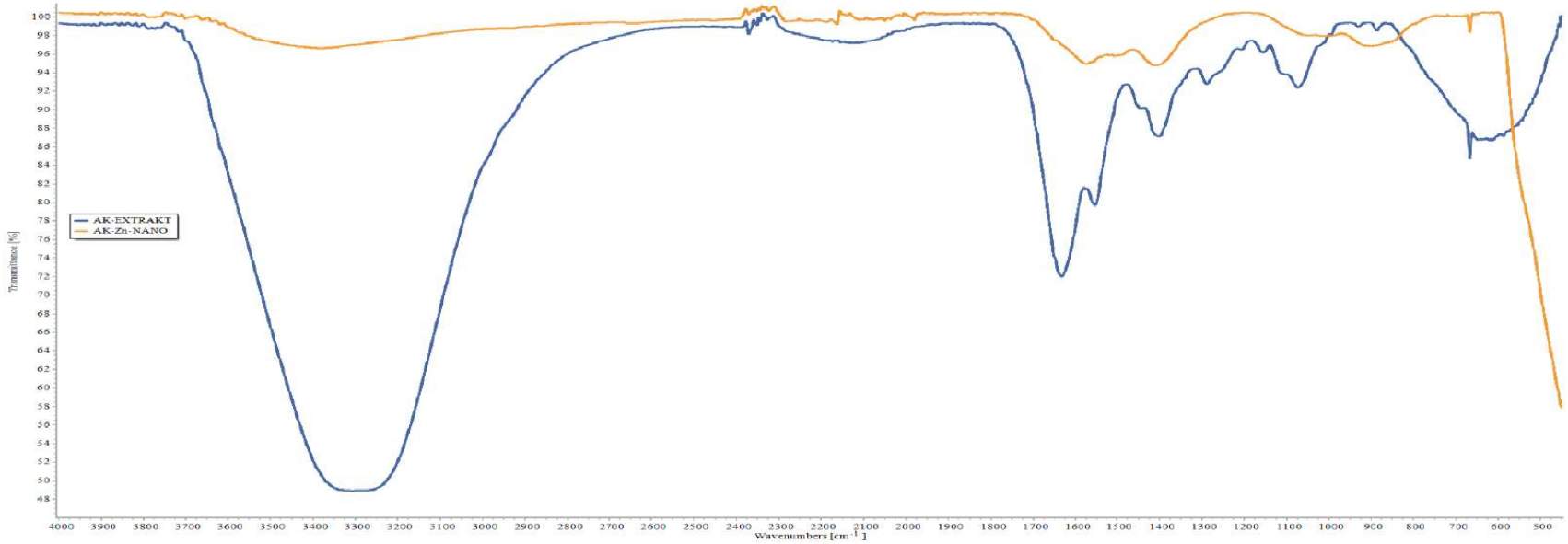
- ✓ **CuONPs** karakteriše **izražena aglomeracija i manje uniformna morfologija.**
- ✓ **Šira raspodela veličina** u poređenju sa AgNPs.
- ✓ Veća sklonost bakra ka **oksidaciji.**

FTIR analiza nanočestica i biljnih ekstrakata

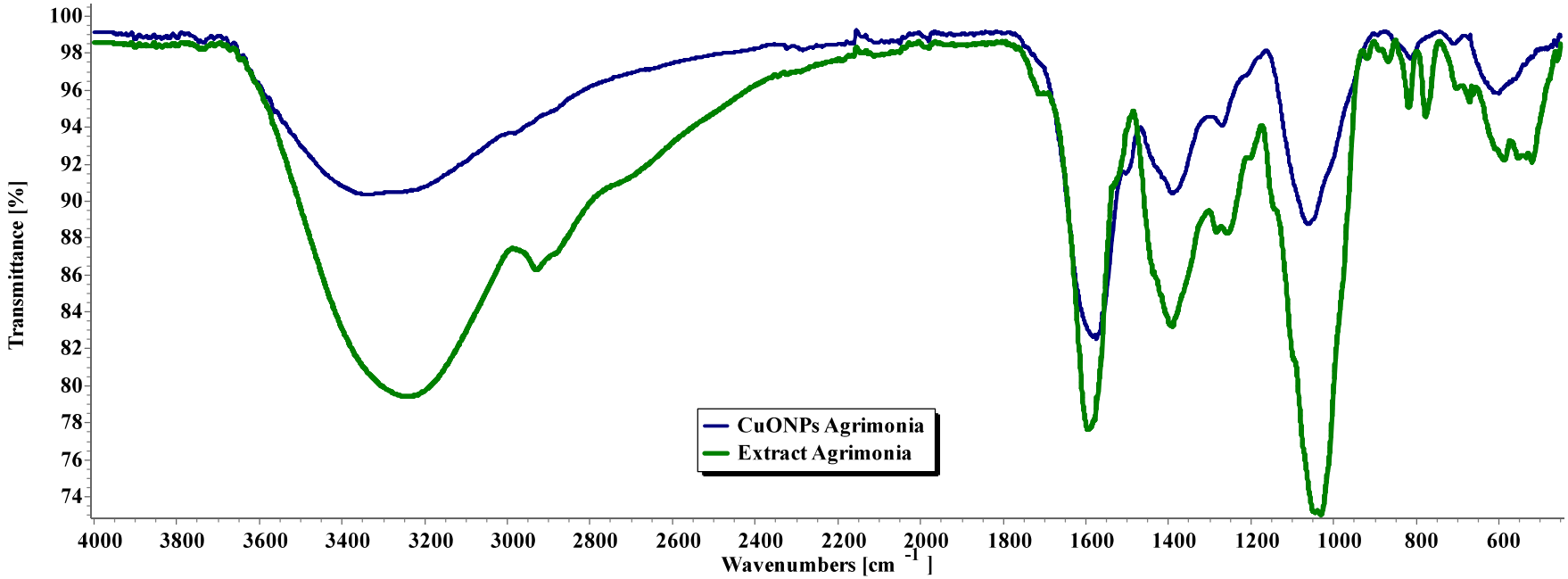
- ✓ **FTIR analiza** korišćena je za identifikaciju funkcionalnih grupa biomolekula uključenih u redukciju i stabilizaciju nanočestica.
- ✓ U spektrima biljnih ekstrakata uočene su karakteristične apsorpcione trake koje odgovaraju: **O–H, C=O i C–O vibracijama.** Prisustvo ovih traka ukazuje na **fenole, flavonoide** i druga bioaktivna jedinjenja u biljnom ekstraktu.
- ✓ Ove promene potvrđuju učešće biomolekula u **procesu redukcije i stabilizacije nanočestica.**



FTIR spektri: ekstrakta Agrimonia eupatoria i odgovarajućih AgNPs - ***izraženiji pomeraji FTIR traka***



FTIR spektri ekstrakta Agrimonia eupatoria i odgovarajućih ZnONPs - ***umerene promene intenziteta i položaja traka***



FTIR spektri ekstrakta Agrimonia eupatoria i odgovarajućih CuONPs - ***najmanje izražene promene***

Komparativna analiza sintetisanih nanočest



- ✓ **AgNPs, ZnONPs i CuONPs nanočestice** pokazuju **značajne razlike** u mehanizmu formiranja i fizičko-hemijskim svojstvima.
- ✓ **AgNPs** nastaju **direktnom redukcijom** jona srebra pod blagim reakcijskim uslovima.
- ✓ **ZnONPs** i **CuONPs** formiraju se preko **hidroksidnih intermedijera** uz naknadno nastajanje oksidnih struktura.
- ✓ Srebrne nanočestice **AgNPs** odlikuju se **bržom kinetikom formiranja** i većom koloidnom stabilnošću.
- ✓ Oksidne nanočestice (**ZnONPs i CuONPs**) zahtevaju **alkalne uslove** sinteze i pokazuju sporije formiranje.
- ✓ Razlike u mehanizmu sinteze direktno utiču na **morfologiju, optička svojstva i stabilnost nanočestica.**
- ✓ **Priroda metalnog prekursora** predstavlja jedan od ključnih faktora koji određuje karakteristike nanočestica dobijenih zelenom sintezom.

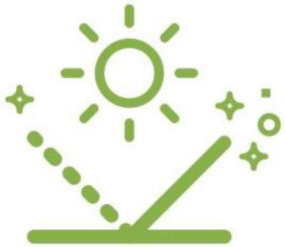
Tabela 1. Ključne razlike u zelenoj sintezi i svojstvima Ag, ZnO i CuC nanočestica

Svojstvo	AgNPs	ZnONPs	CuONPs
Dominantna faza	Ag^0 (metalna)	ZnO (oksidna)	CuO (oksidna)
Mehanizam formiranja	Direktna redukcija	Hidroksid → oksid	Hidroksid → oksid
Reakcioni uslovi	Blagi (pH ≈ 6)	Jako alkalni (pH 12–13)	Umereno alkalni (pH ≈ 8)
Brzina formiranja	Brza	Umerena	Umerena
UV–Vis karakteristika	maksimum (400–450 nm)	maksimum (~365 nm)	Široka apsorpciona traka
Stabilnost	Visoka	Umerena	Niža
Glavne primene	Antimikrobna aktivnost, kataliza	Fotokataliza, senzori, remedijacija životne sredine	Kataliza, antimikrobna aktivnost, zaštita životne sredine

Potencijalna primena

- ✓ **AgNPs**
  - **antimikrobni agensi**
  - kataliza
  - biomedicinske primene
- ✓ **ZnONPs**
  - **fotokataliza**
  - senzori
  - remedijacija životne sredine
- ✓ **CuONPs**
  - **katalitički procesi**
  - antimikrobna aktivnost
  - zaštita životne sredine.







Zaključak

- ✓ **Priroda metalnog prekursora** određuje put sinteze i konačna svojstva nanočestica.

- ✓ **AgNPs** nastaju direktnom redukcijom Ag^+ jona do Ag^0.
- ✓ **ZnONPs** i **CuONPs** formiraju se preko hidroksidnih intermedijera i oksidnih faza.

- ✓ **TEM i FTIR** analize potvrdile su ključnu ulogu biomolekula iz biljnih ekstrakata u procesima redukcije i stabilizacije nanočestica.

- ✓ Najizraženije interakcije između biomolekula i površine nanočestica uočene su kod **AgNPs.**

INSTITUT ZA
INFORMACIONE
TEHNOLOGIJE
KRAGUJEVAC

NAŠ TIM

Zelena sinteza nanočestica – od prirode do naprednih rešenja



dr Mirjana Grujović
viši naučni saradnik



dr Katarina Marković
viši naučni saradnik



dr Jelena Katanić Stanković
viši naučni saradnik



dr Ana Kesić
viši naučni saradnik

Naš cilj je da kroz zelenu sintezu razvijamo **održive, bezbedne i efikasne** nanočestice primenom prirodnih resursa, u funkciji **nauke, tehnologije** i **zaštite životne sredine**.

ODRŽIVOST | INOVACIJE | NAUKA | BUDUĆNOST

Zahvalnica

Ovaj rad podržan je od strane Ministarstva nauke, tehnološkog razvoja i inovacija Republike Srbije (бр. 451-03-33/2026-03/200378).

Takođe se zahvaljujemo Institutu za informacione tehnologije Kragujevac, Univerzitet u Kragujevcu, na pruženoj podršci i obezbeđenim uslovima za realizaciju ovog istraživanja



Ministarstvo nauke, tehnološkog razvoja i inovacija Republike Srbije



Institut za informacione tehnologije Kragujevac Univerzitet u Kragujevcu



akesic@uni.kg.ac.rs

Hvala na pažnji!